

Climate: Earth's Dynamic Equilibrium, Part 2



PA STEM
review session

CCIU

April 30, 2016

High-school standard HS-ESS2-2 highlights the role that feedbacks play in Earth's climate

PA STEM
Science

HS-ESS2-2 Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.

[Clarification Statement: Examples should include climate feedbacks, such as how an increase in greenhouse gases causes a rise in global temperatures that melts glacial ice, which reduces the amount of sunlight reflected from Earth's surface, increasing surface temperatures and further reducing the amount of ice. Examples could also be taken from other system interactions, such as how the loss of ground vegetation causes an increase in water runoff and soil erosion; how dammed rivers increase groundwater recharge, decrease sediment transport, and increase coastal erosion; or how the loss of wetlands causes a decrease in local humidity that further reduces the wetland extent.]

Climate science distinguishes between climate forcings and climate feedbacks

PA STEM
Science

• **Climate forcing**—any mechanism *external* to Earth's climate system that causes it to change from its equilibrium condition

• **Climate feedback**—any mechanism *internal* to Earth's climate system that acts in response to a change from its equilibrium condition

◦ **Positive feedback**—any response that *acts in the same direction* as the original change (i.e., further from equilibrium)

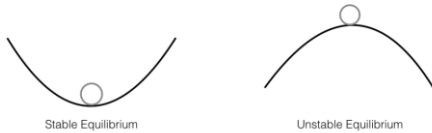
◦ **Negative feedback**—any response that *acts in the opposite direction* as the original change (i.e., back towards equilibrium)

Positive and negative feedbacks are much more general than climate science

PA STEM
Science

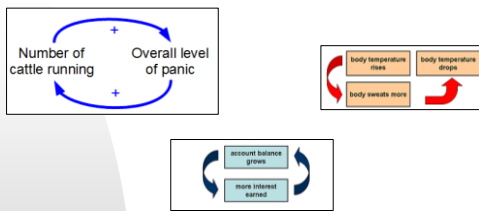
Example—A ball rolling on a hill or in a valley

Which is a positive feedback and which is negative? Why?



Feedbacks often create feedback loops, where a forcing causes a feedback, which induces another feedback, amplifying the original effect

PA STEM
Science



Determine whether each of these loops is a positive or negative feedback

Can you think of more examples?

Complexity of Earth's climate system is due mainly to a large number of feedback loops

PA STEM
Science

Examples:

• Water vapor feedback

Increased temperature → more water vapor → more infrared absorption → increased temperature

• CO₂/precipitation feedback

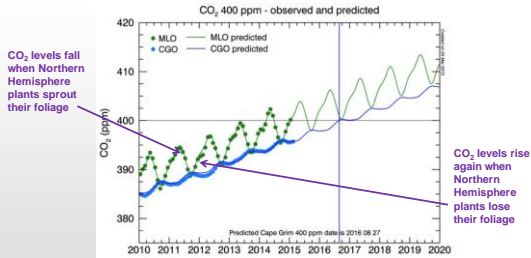
Increased CO₂ → higher temperature → more rain → more CO₂ dissolves in H₂O → less CO₂

• CO₂/biomass feedback

• Insolation/ice cap feedback

For the CO₂/biomass feedback, increased CO₂ helps plants grow, causing more CO₂ absorption

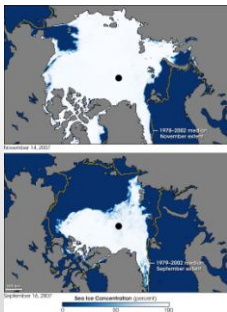
PA STEM
Science



An example of CO₂ absorption by plants under warming conditions is seen annually in global CO₂ levels

For the insolation/ice cap feedback, increased sunshine melts more ice, reducing albedo and causing more sunshine to be absorbed

PA STEM
Science

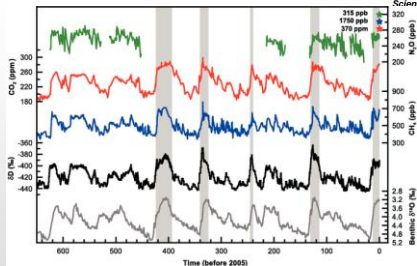


When sea ice melts, it exposes dark, heat-absorbent open ocean, which in turn

- decreases net albedo
- increases heat absorption
- induces further melting
- further decreases net albedo
- further increases heat absorption

A series of complex feedbacks is responsible for Earth's ice-age cycle

PA STEM
Science

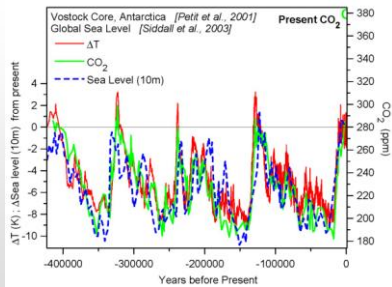


(Ice core and ocean sediment core data. Grey bars represent interglacial periods.)

Milankovitch cycle → warming → CO₂ outgases → more warming → water vapor

Ice core data clearly show that CO₂ and warming are linked, but that CO₂ changes lag the initial warming

PA STEM
Science



Do you see evidence of a lag? Is CO₂ the response or the initial cause of the warming?

Two more standards focus on the impacts of climate change and the impact of human activity

PA STEM
Science

HS-ESS3-5 Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.

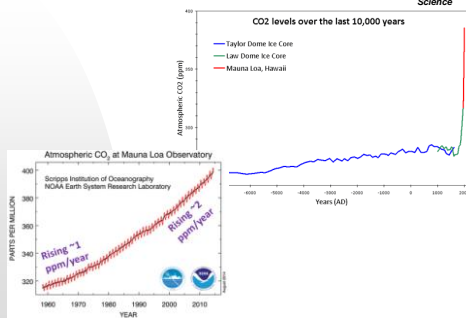
[Clarification Statement: Examples of evidence, for both data and climate model outputs, are for climate changes (such as precipitation and temperature) and their associated impacts (such as on sea level, glacial ice volumes, or atmosphere and ocean composition).]

HS-ESS3-6 Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.

[Clarification Statement: Examples of Earth systems to be considered are the hydrosphere, atmosphere, cryosphere, geosphere, and/or biosphere. An example of the far-reaching impacts from a human activity is how an increase in atmospheric carbon dioxide results in an increase in photosynthetic biomass on land and an increase in ocean acidification, with resulting impacts on sea organism health and marine populations.]

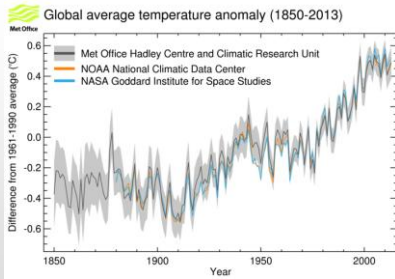
Dramatic increases in CO₂ over the last century clearly imply its origin in human activity

PA STEM
Science



In the last century average surface temperatures on Earth have increased by about 1.0°C (1.8°F)

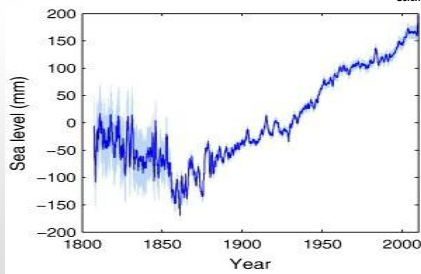
PA STEM
Science



Approximately half of this increase is likely caused by human activity

Tide gauge data show that sea level has increased steadily over the last 150 years

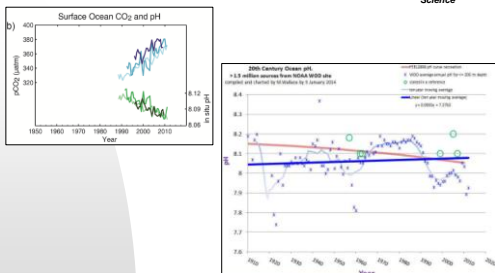
PA STEM
Science



Most of this rise comes from thermal expansion of ocean water

Increased CO₂ in the atmosphere is getting absorbed in the oceans and changing the pH

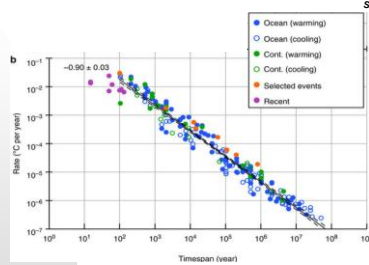
PA STEM
Science



Ocean pH may have fallen from 8.2 (base) to 8.1 in the last century

Despite frequent claims to the contrary, recent observed warming is not occurring faster than natural warming in Earth's past

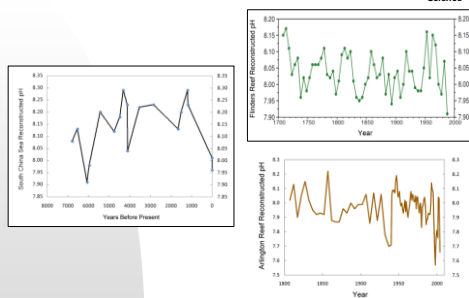
PA STEM
Science



The long-standing perception of "unprecedented" warming rates is due to limited resolution in paleoclimate reconstructions [Kemp et al., Nat. Comm. 6, 8890 (2015)]

Rapid change of ocean pH is also seen over multiple time scales in various reconstructions

PA STEM
Science



Even so, the role of humans in climate change is unprecedented, sufficient reason for concern

PA STEM
Science

